AOSN MURI: Deep Water Docking for the Autonomous Oceanographic Sampling Network

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LONG TERM GOALS

To create and demonstrate a reactive survey system, capable of long-term unattended deployments in harsh environments. We refer to such a system as an Autonomous Ocean Sampling Network (AOSN). Our specific task is concerned with docking the vehicle to a mooring and autonomously transferring data from it and recharging it batteries.

OBJECTIVES

Our work has focussed on the design of the docking system on the AUV as well as the mooring to accomplish the tasks associated with returning the vehicle to a dock after it has completed a mission, the servicing of the vehicle to include the tasks associated with the transfer of data and power between the vehicle and mooring, and the interaction of the vehicle to support it for the purposes of long term unattended deployments.

APPROACH

Figures 1(a) and (b) are an artist's rendition of the docking system as it exists today. The AUV drives into a pole on the dock such that a latch mounted on the bow of the AUV trips and ensures

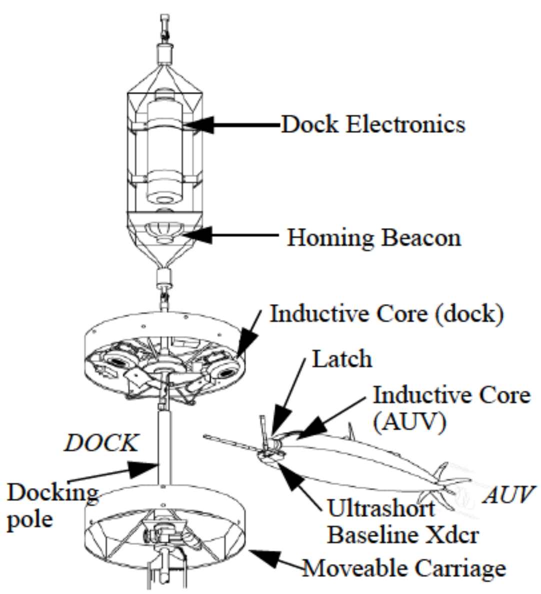

Figure 1(a). The Docking System

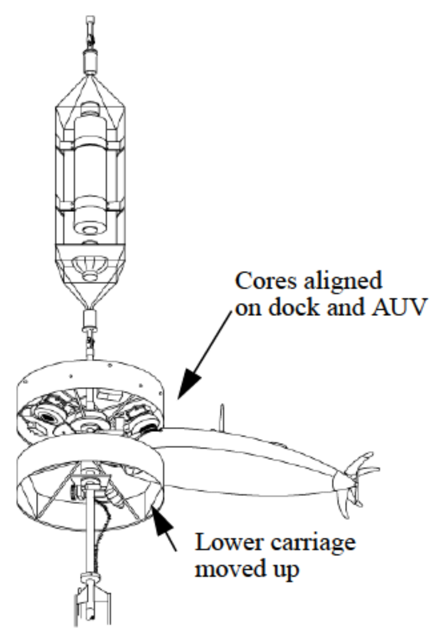

Figure 1(b). A Docked AUV

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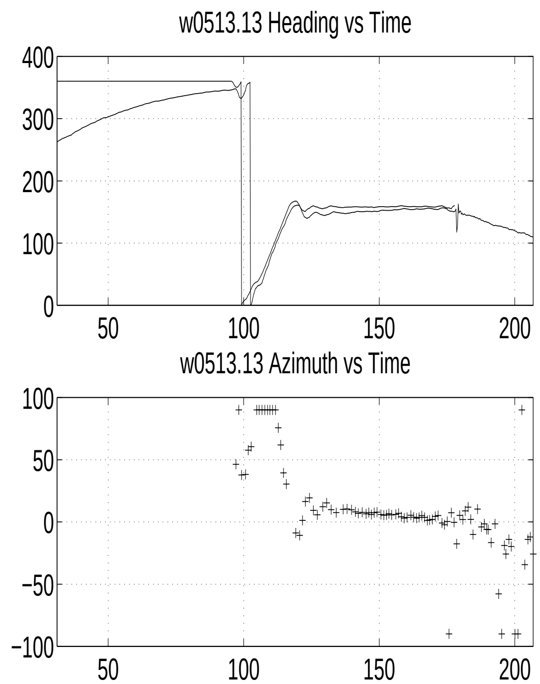

Figure 2. Homing into the Dock

that it is captured by the dock. The lower moveable carriage on the dock is then driven up to force inductive cores on the AUV and the dock into alignment allowing us to transfer data and power between the AUV and dock.

WORK COMPLETED

In the past year we have demonstrated the following:
(1) The ability to repeatedly and consistently home in on and latch the MIT Odyssey IIB class AUV on to a dock in shallow water in sea trials of off the R/V Cape Hatteras.
(2) The ability to transfer power and data to the Odyssey IIB class AUV in trials of the Woods Hole dock, off of the R/V Cape Hatteras, and the R/V Oceanus.

RESULTS

Sea Trials off the *R/V Cape Hatteras*

In May off this year we participated in a cruise in Cape Cod Bay to test and demonstrate our approach to docking by suspending a dock off the side of the ship and conducting a series of vehicle missions.

For the purposes of analysis and implementation the tasks associated with docking a vehicle to a mooring and transferring power and data to and from it were broken up functionally in the following manner.

Homing — On the dock a homing beacon sends out a barker code at 2Hz. An ultra-short baseline system on the vehicle uses this signal to calculate an azimuth and elevation to the beacon which it uses to home in on the dock.We have incorporated a successful strategy for retrying the homing behaviour if we miss on an initial approach. Figure 2 shows one run where the vehicle turned on the beacon, acquired it almost immediately, turned around from its initial heading of 350° to a heading of 150° and then successfully docked to the vehicle on its first approach. We typically began homing from 100m-200m away though much longer ranges of up to 1 km in shallow water were obtained.

Docking — The AUV goes into its docking behavior when its latch is tripped. The latch consists of a vee-shaped, bilaterally symmetrical, titanium latch body with two fixed tines and a pivoting titanium capture bar. The docking pole on the mooring enters the latch anywhere between the two fixed tines of the latch body and is directed toward the AUV centerline, taking advantage of the forward motion of the AUV. The pole then pushes the capture bar aside and enters a nest in the latch body, where an extension spring closes the capture bar around the pole. The AUV may latch onto the pole anywhere within a one-meter length. When latched, the geometry of the capture bar ensures that the AUV remains safely mated to the pole and is unable to force its way out. To unlatch, a solenoid briefly opens the capture bar, allowing the pole to escape the latch.

Core Alignment — The cores are aligned by driving a motorized carriage up the pole so that it forces the vehicle to slide up the pole. Guiding struts on the top assembly force the pucks on the vehicle and the dock into alignment. Magnetic switches associated with the pucks provide an independent mechanism for determining when the pucks are in alignment. The magnetic switches are tripped only within a radius of a quarter of an inch. To achieve this tight tolerance it was sometimes necessary to cycle the carriage up and down the pole more than once.

Table 1:

Run #	Homing	Latching	Core Alignment	Power Transfer	Undocking	Comments
w0513.06	Yes / Yes	Yes / Yes	Yes / Yes	Yes / Yes	Yes / Yes	
w0513.07	Yes / Yes	Yes / Yes	Yes / Yes	Yes / Yes	Yes / Yes	
w0513.08	Yes / Yes	Yes / Yes	Yes / Yes	Yes / Yes	Yes / Yes	
w0513.09	Yes / Yes	Yes / Yes	Yes / Yes	Yes / Yes	Yes / Yes	
w0513.10	Yes / Yes	Yes / Yes	Yes / Yes	Yes / Yes	Yes / Yes	
w0513.12	Yes / Yes	Yes / Yes	Yes / Yes	Yes / Yes	Yes / Yes	
w0513.13	Yes / Yes	Yes / Yes	Yes / Yes	Yes / Yes	Yes / Yes	
w0513.14	Yes / Yes	Yes / Yes	Yes / Yes	Yes / Yes	Yes / No	Low batteries prevented undocking

Power Transfer — Once the pucks are in alignment, power may be transferred between the dock and the AUV. In the runs described here we would typically transfer power for about ten minutes. We saw efficiencies of about 80% when transferring power across the whole system.

Data Transfer — The data transfer component of the dock was not working during this cruise due to hardware problems.

Undocking — The solenoid was energized and a combination of thrust maneuvers powered the AUV away from the dock.

Analysis of a series of typical runs — Table 1 summarizes the results from seven consecutive runs

that were made by the AUV on May 13, 1997. For each of the functional sub-blocks that were identified we show whether the mission attempted to achieve the functionality associated with that block and whether it was successful in doing so. Each mission took the vehicle away from the ship on a specified heading. The vehicle then went into its homing behavior. It was commanded to home until it docked and then stayed docked for a fixed period of time. During this fixed period an operator ran a program on the dock which brought the inductive cores on the AUV and the dock into alignment. Power transfer between the dock and the vehicle was then initiated for typically several minutes. The carriage on the dock was then brought down prior to the vehicle undocking.
Overall we can see that six of the seven missions were complete successes and that the last failure to undock was caused by a low state of the battery charge on the AUV.

Sea Trials off the *R/V Oceanus*

Based on our experiences in using our prototype system in shallow water in Cape Cod Bay we refined our hardware and approach to test out our capabilities on a dock integrated onto a deep water mooring. Key features for this set of sea trials included the following. The dock was redesigned to consist of only one puck instead of three; a surface link was added to allow remote access to the dock and hence the vehicle via satellite communications; a variety of oceanographic sensors were incorporated onto the dock and these included temperatures sensors, a depth sensor, a precision attitude measurement package, an acoustic modem, a long baseline acoustic navigation transponder, and a current measurement device. Figure 3 shows the current generation of dock.

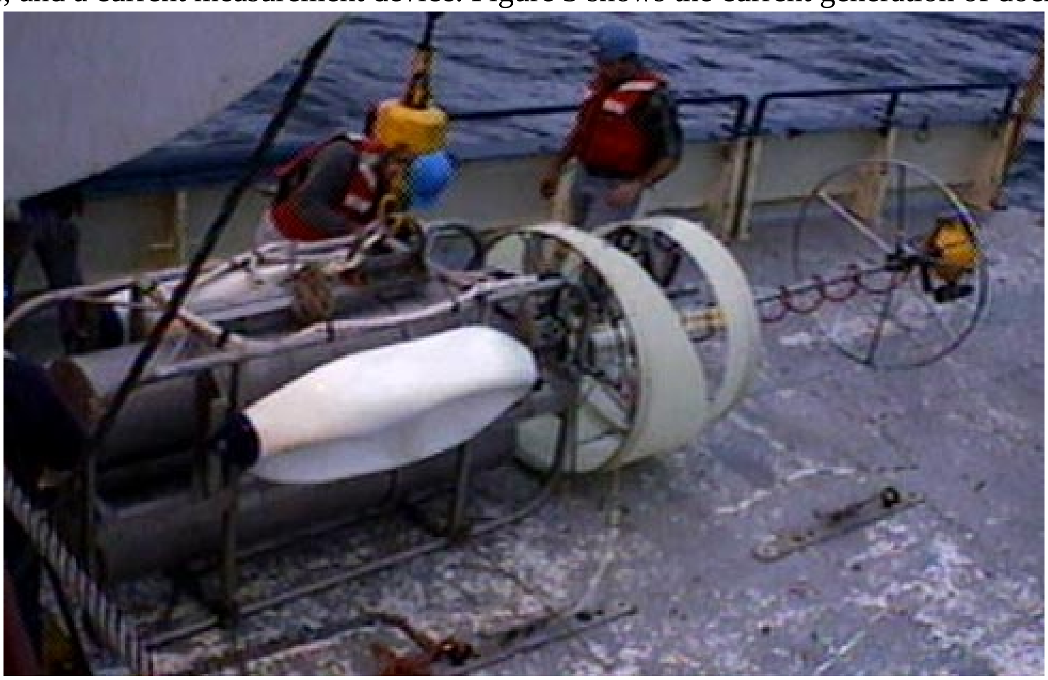

Figure 3. The current generation of deep water dock

The entire dock was integrated into a full ocean depth mooring that was deployed in ~2700m of water in trials conducted off the R/V Oceanus in October. Bad weather prevented us from homing and docking to the mooring once it was deployed but we did exercise the functionality of each of the components in the dock (described above) for a number of days. The data transfer capability that was not exercised in May worked flawlessly. 160 files which represented a total of 50 Megabytes worth of AUV data were transferred between the dock and the vehicle without failure more than a dozen times.

IMPACT/APPLICATIONS

This work represents the first example of a unattended dock with the capabilities of data tranfer, power transfer and an integrated satellite hookup. Our work is now focussing on expanding our capabilities to allow for long term unattended deployments. The software for such tasks is already in place and undergoing testing using a dock and an Odyssey IIB class AUV deployed off the Woods Hole Oceanographic Institution’s pier. We hope to demonstrate these capabilities in the Labrador Sea and in Massachusetts Bay during the upcoming year.

RELATED PROJECTS

This project is part of the Multidisciplinary University Research Initiative: “Real-Time Oceanography with Autonomous Ocean Sampling Networks: A Center for Excellence”

REFERENCES

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2. http://www.dsl.whoi.edu/~hanu/docking.html The docking home page